

THEORETICAL ECONOMIC POTENTIAL OF THE SPANISH PREMIUM TARIFF FOR SOLAR THERMAL POWER PLANTS

Michael Wittmann, Markus Eck, Tobias Hirsch, Robert Pitz-Paal

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Presentation Overview

- Legal Background
- System definition
- Results
- Conclusion & Outlook

Legal Background

Electricity market in Spain

Royal Decree 661 / 2007

allows Operator to choose between two tariff options
(tariff can be changed every year by operator)

➤ Fixed Tariff (*tarifa regulada*)

- one tariff:
24 hours per day and 7 days
a week
- feed-in right

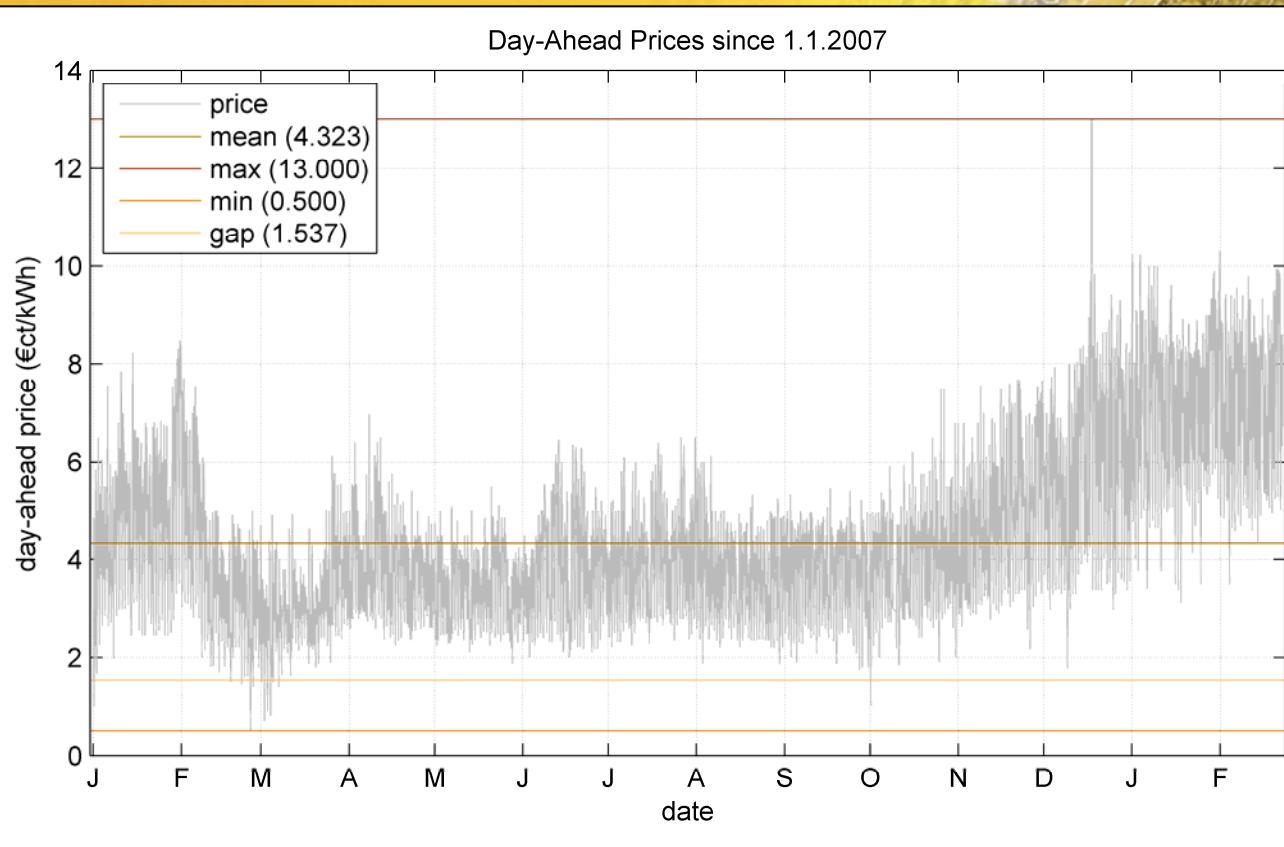
➤ Premium Tariff (*prima*)

- participating at free
electricity market:
hourly changing electricity
prices
- no feed-in right
- grid auxiliary services

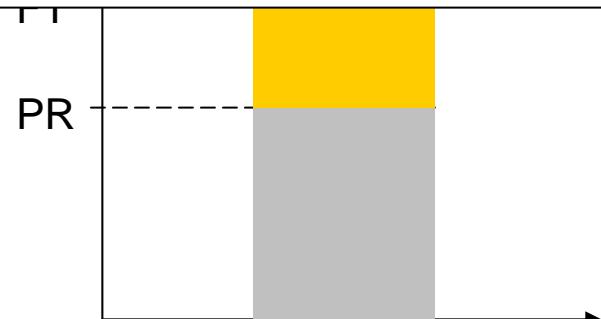
Legal Background Electricity market

Premium Tariff

- a lower base tariff
- the plant operator
- operator acts as agent and loses right



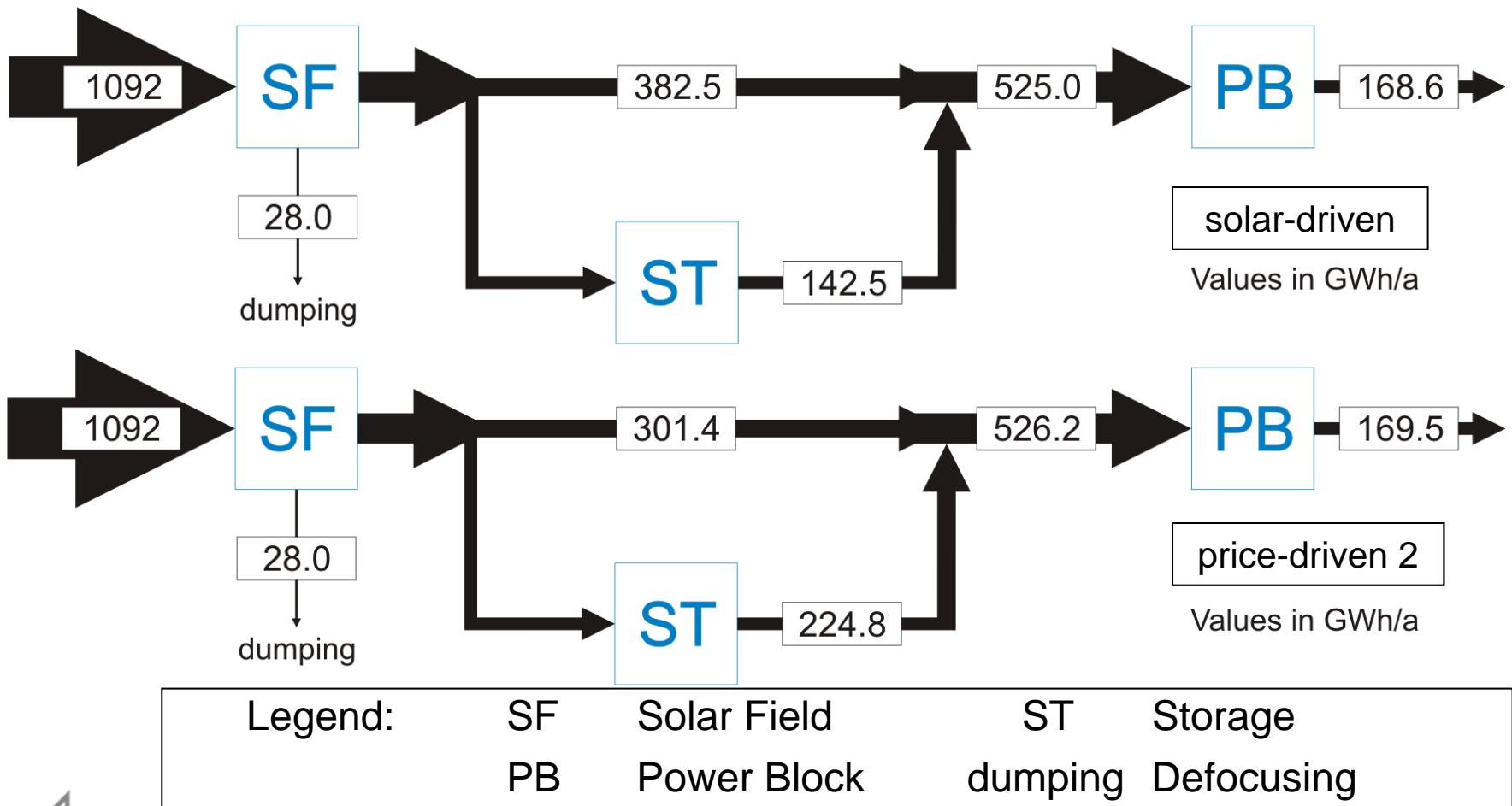
- current legal foundation RD 661/2007
 - feed-in tariff **26.9375 ct/kWh**
 - premium **25.4000 ct/kWh**
 - gap **1.5375 ct/kWh**



System definition

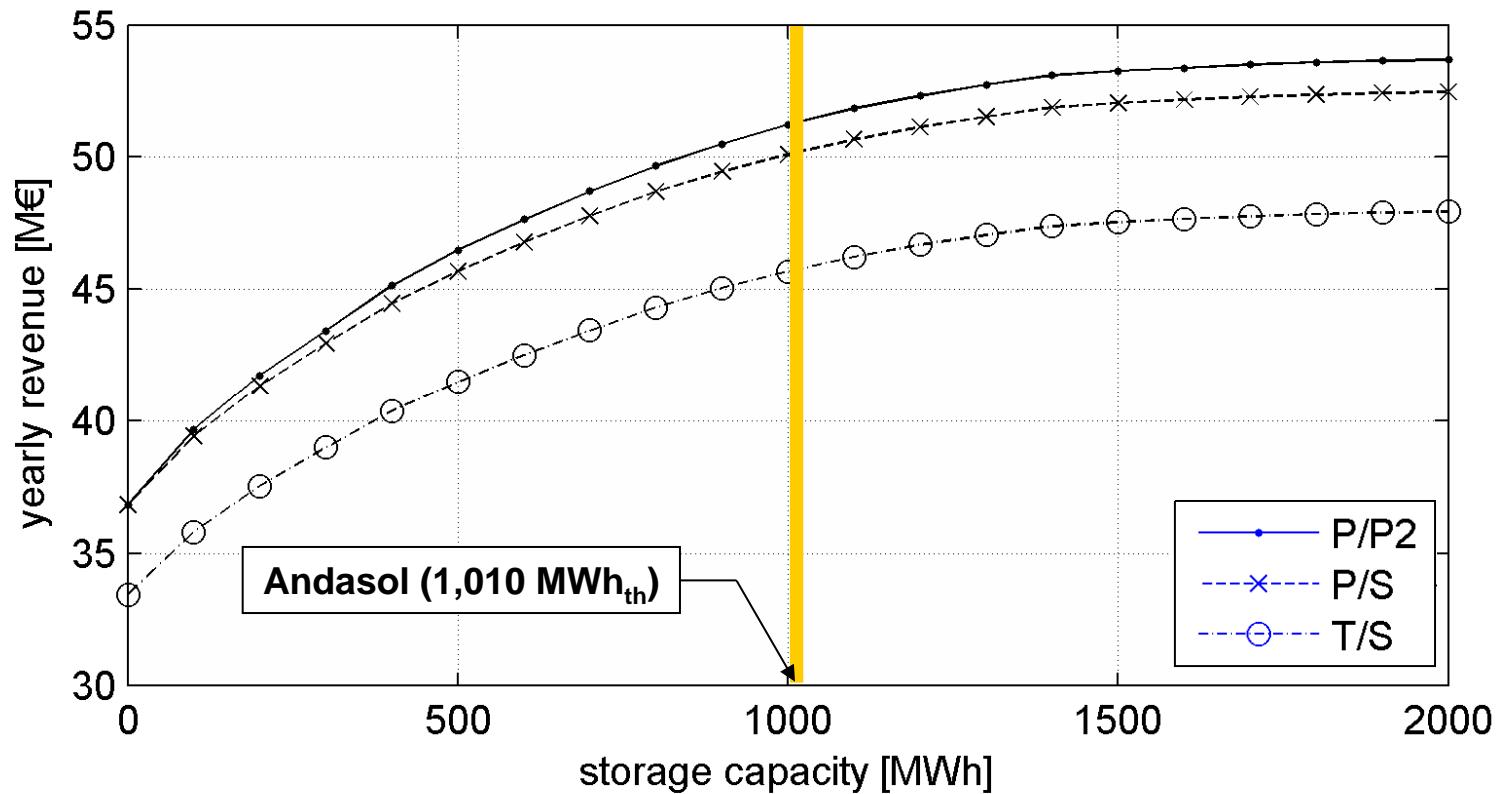
- Plant
 - oriented at Andasol-1 specifications (i.e. 50 MW plant w/7.5 h Storage System)
 - solar field characteristics according to LUZ (LS-2-collectors)¹
 - location: 37°2' N, 3°4' W, i.e. Gaudix (Province Granada, Spain)
- Operation strategies
 - solar-driven (reference)
 - price-driven (optimized)
 - maximizes daily revenue
- Assumptions
 - steady-state models
 - exergetically and energetically ideal storage (i.e. adiabatic, direct)
 - perfect forecast accuracy
- Examined Years
 - 2002 („normal“ year), 2005 (high prices and high irradiation)

Assessment of the theoretical economic potential Energy Flow for different Operation Strategies



Assessment of the theoretical economic potential

Economic Potential



Influence of real Forecast Information on the Economic Potential - Overview

- same Plant
- same Optimization Objective
- same Operation Strategy
- same Perfect Price Forecast
- altered Weather Forecasts
real: ECMWF¹, AFSOL²; artificial: persistence model

Assessment on selected Weather Situations

- clear sky days
- partially overcast days

Detailed results to be published as:

Wittmann M., Breitkreuz, Schroedter-Homscheidt, Eck: "Case-Studies on the Use of Solar Irradiance Forecast for Optimized Operation Strategies of Solar Thermal Power Plants". In: IEEE J-STARS, 2008

¹Morcrette, J.-J.: "Radiation and cloud radiative properties in the ECMWF operational weather forecast model". In: Journal of Geophysical Research. 96 (1991), S. 9121-9132

² Breitkreuz, H. et al., "Application of Aerosol Forecasts for Solar Energy Industries". In: Geophysical Research Abstracts Vol. 9, 4th EGU General Assembly, EGU-2007-A-02573, Vienna, Austria, 2007.

Influence of real Forecast Information on the Economic Potential – Clear Sky Days

TABLE I
Stock Exchange Revenues from July 27–28

Forecast Model	Premium Tariff				Fixed Tariff
	[S] Revenue w/Solar- driven Strategy (k€)	Optimality ^a	[P1] Revenue w/Price- driven Strategy (k€)	Optimality ^a	[S] Revenue w/Solar-driven Strategy (k€)
AFSOL	72.1	99.9 %	75.8	99.9 %	
ECMWF	46,8	64.8 %	51.1	67.3 %	
persistence	71.9	99.6 %	75.6	99.6 %	
perfect	72.2	100 %	75.9	100 %	31.1

time (h)

^a The optimality ratio should not be used for the determination of general forecast quality, due to the significant impact of the ECMWF deviations. July 27th and 28th (a). Deviations of forecast models are shown in (b).

Influence of real Forecast Information on the Economic Potential – Overcast Days

TABLE II
Stock Exchange Revenues from July 19–21

Forecast Model	Premium Tariff				Fixed Tariff
	[S] Revenue w/Solar- driven Strategy (k€)	Optimality ^a	[P1] Revenue w/Price- driven Strategy (k€)	Optimality ^a	[S] Revenue w/Solar-driven Stragegy (k€)
AFSOL	46.9	86.1 %	46.4	74.0 %	21.2
ECMWF	53.5	98.2 %	58.2	92.8 %	
Persistence	51.8	95.0 %	59.4	94.7 %	
perfect	54.5	100 %	62.7	100 %	

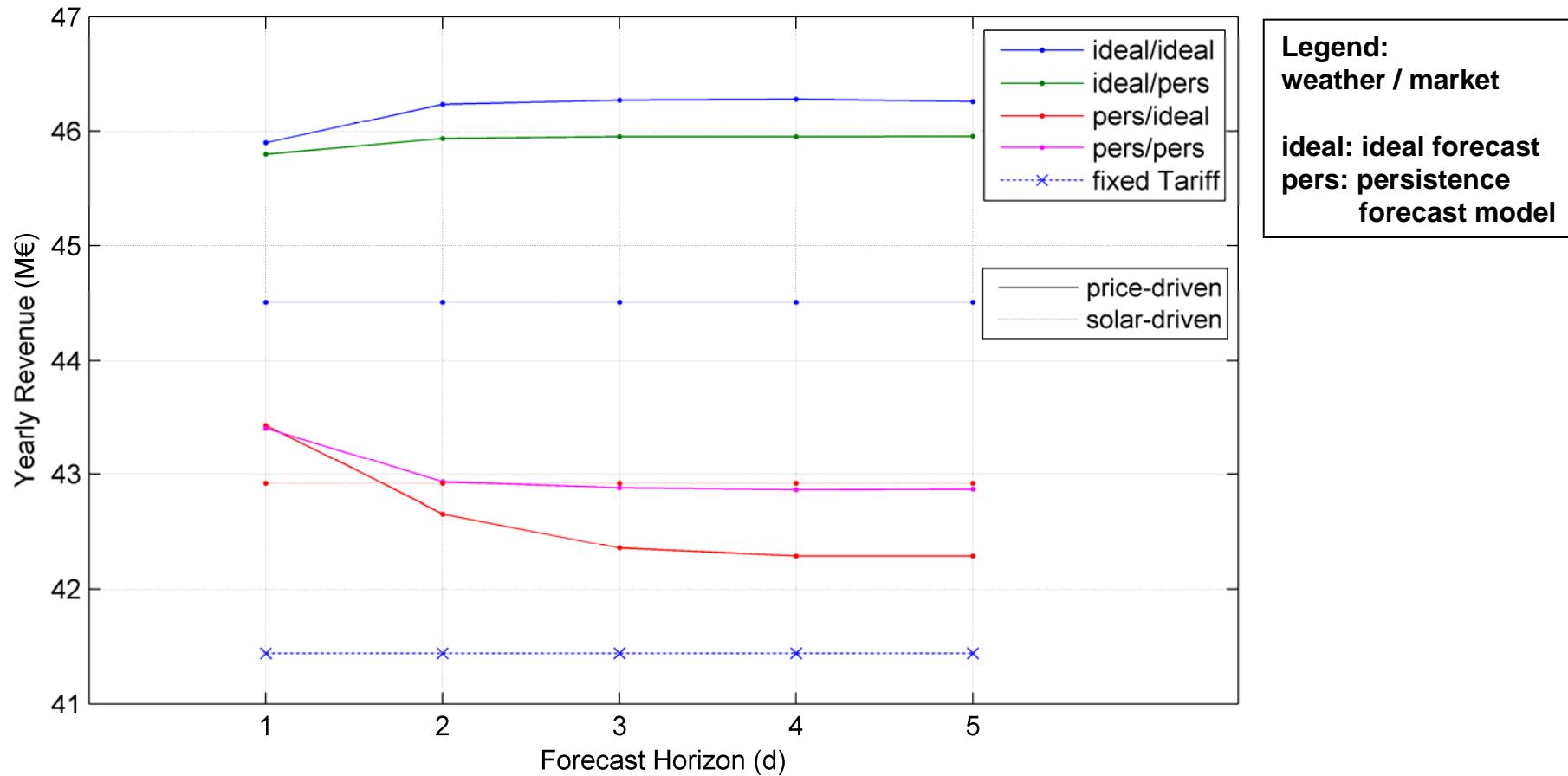
-ahead market

54 60 66 72

DL forecast (—)
19th–21st (a).
wn in (b). The
inish day-ahead

^a The optimality ratio should not be used for determination of general forecast quality, due to the significant impact of the time of deviations during the day.

Influence of Persistence Forecast on the Yearly Economic Potential – Results (Year 2002)



Conclusions

- premium model motivates operators of solar power plants to participate at the market like conventional plants do
- the change from the tariff model to the premium model offers a significant economic potential
- smart, price-driven operation strategies show better performance than standard solar-driven strategies

Outlook

- updated forecasts and participation at intraday markets promise lower penalties and therefore further raise in revenue
- developed setup of optimized operation strategies are transferable to different power plant and storage configurations

The authors would like to thank Solar Millennium AG
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Thank you for your attention!

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Backup Slides

- Detailed Plant / Model Specifications
- Optimization problem
- Stock Price Time Series for 2002 and 2005

Detailed Plant / Model Specifications (1)

» General

- » Location: Guadix, Spain ($37^{\circ}2' N, 3^{\circ}4' W$)
- » Ambient Temperature: 25 °C (constant)
- » Overall Availabilities: 100 %
90 % (for persistence forecast results)

» Meteorology

- » Yearly Irradiance 2002: 2,141 kWh/m²
- » Yearly Irradiance 2005: 2,415 kWh/m²
- » Forecast Accuracy: 100 %

» Day-Ahead Market OMEL

- » Mean Price 2002: 3.74 €-ct/kWh_{electric}
- » Mean Price 2005: 5,37 €-ct/kWh_{electric}
- » Forecast Accuracy: 100 %
- » Deviation Fines: 10 % of current price (symmetric)

Detailed Plant / Model Specifications (2)

↗ Power Block

- ↗ Electric Power: 49.9 MW_{gross}
- ↗ Live Steam: 371 °C / 100 bar
- ↗ Reheat: 370 °C / 16.5 bar
- ↗ Gross Efficiency: 38 % (Design Point)

↗ Solar Field

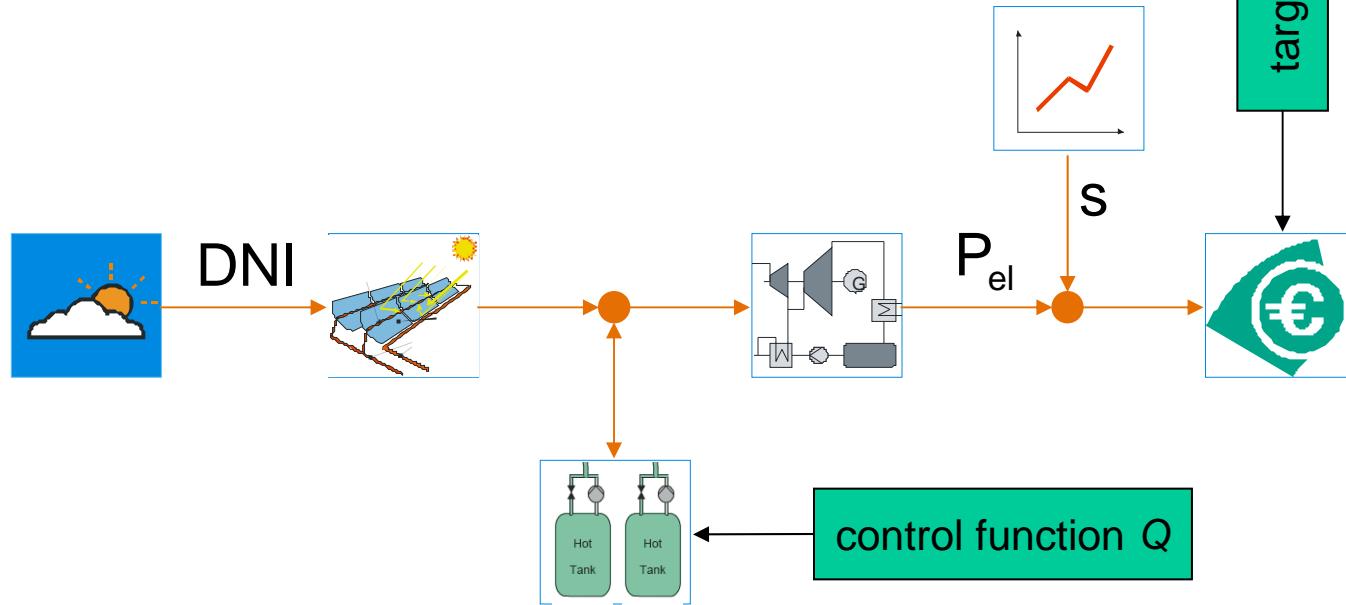
- ↗ Efficiency characteristics of LS-2 collector
- ↗ Collector-Surface: 510,000 m²
- ↗ Absorber Temperature: 300 °C (mean)

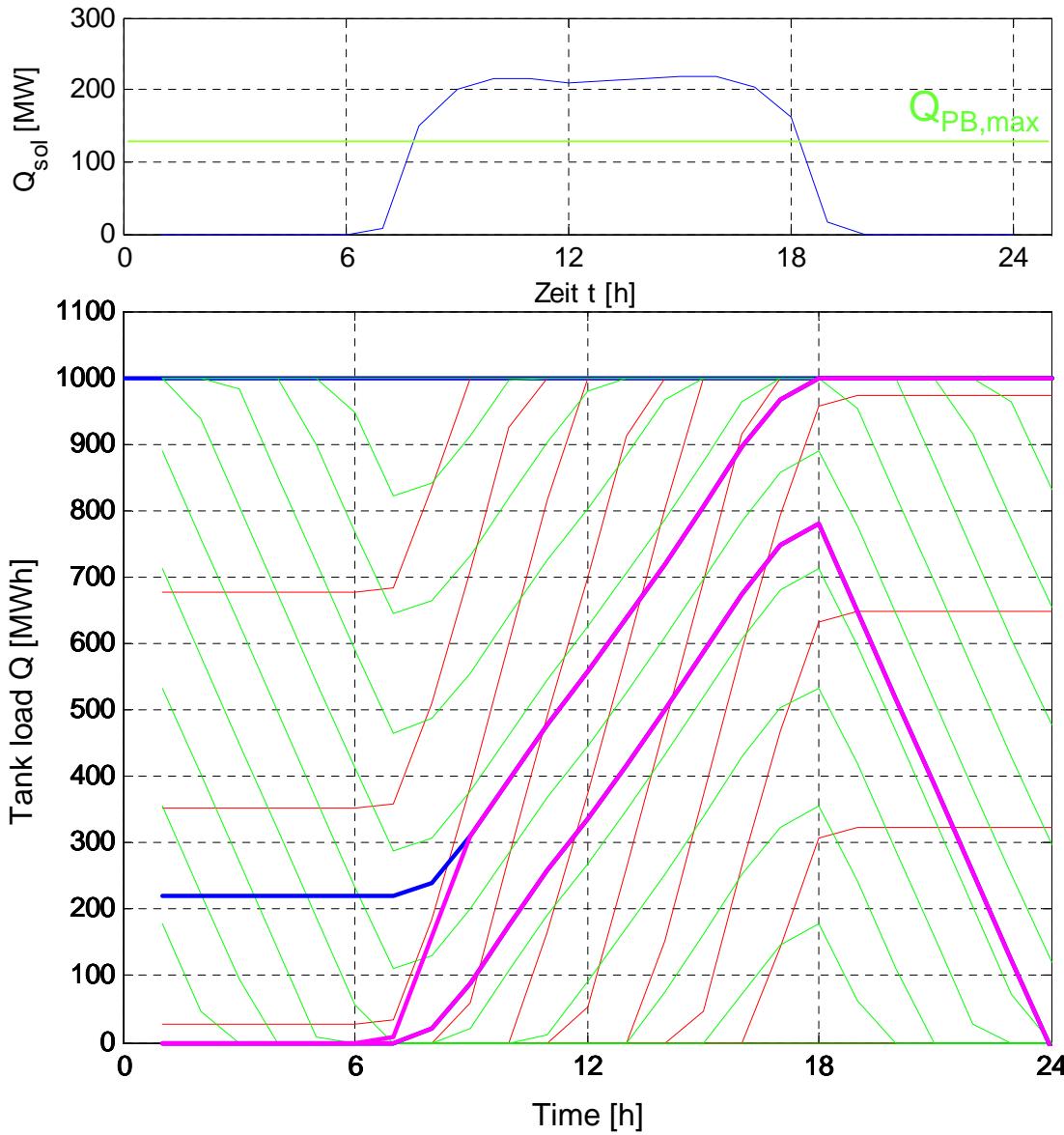
↗ Storage

- ↗ Energetically ideal (adiabatic)
- ↗ Exergetically ideal (direct)
- ↗ Capacity: 1,010 MWh_{thermal} (7.5 h @ 100 % load)

Optimization problem

Plant scheme





$$0 \leq \|Q\|_{\infty} \leq Q_{cap}$$

$$\frac{d}{dt} Q \leq \dot{Q}_{sol}$$

$$\dot{Q}_{min} \leq \frac{d}{dt} Q,$$

$$\text{where } \dot{Q}_{min,i} = \dot{Q}_{sol,i} - \dot{Q}_{PB,max}$$

$$\dot{Q}_{defoc} = \mathbf{0}$$

$$Q_0 = 0$$

Optimization problem

Problem formulation

$$J[\mathbf{x}] \rightarrow \min! \quad \mathbf{x}$$

$$J[\mathbf{x}] = - \int_{t_0}^{t_E} P_{el} s \, dt$$

$$\mathbf{x} = (Q_1, Q_2, \dots, Q_n)^T$$

with

$$0 \leq \|\mathbf{Q}\|_\infty \leq Q_{cap}$$
$$\dot{\mathbf{Q}}_{\min} \leq \frac{d}{dt} \mathbf{Q} \leq \dot{\mathbf{Q}}_{sol}$$

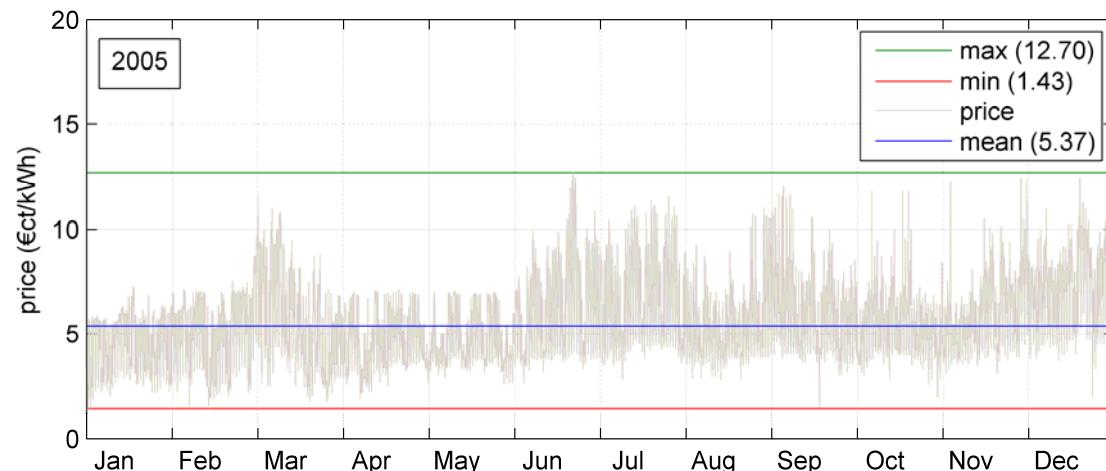
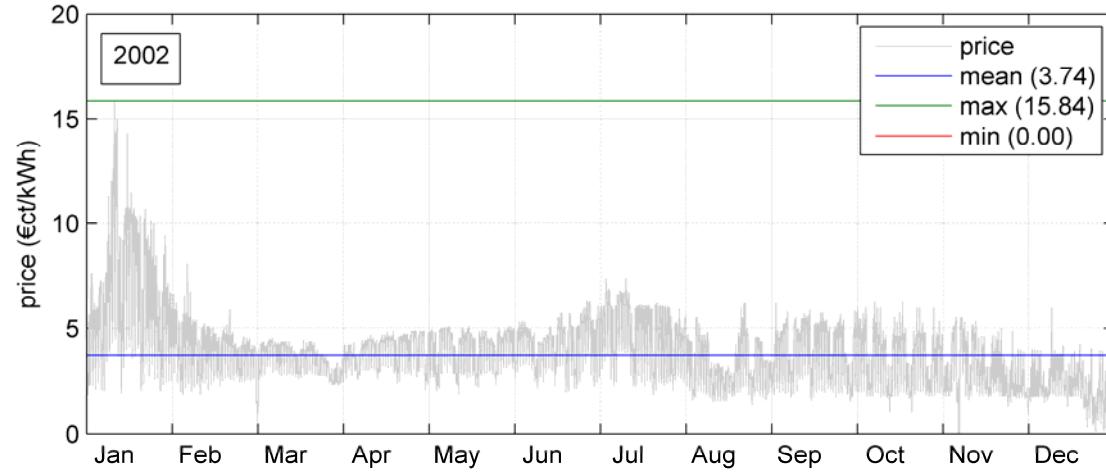
$$\dot{\mathbf{Q}}_{defoc} = \mathbf{0}$$

$$\left. \begin{array}{l} \\ \end{array} \right\}$$

$$\mathbf{g}_{\text{ineq}}(\mathbf{Q}) \leq 0$$

$$\mathbf{g}_{\text{eq}}(\mathbf{Q}) = 0$$

Stock Price Time Series (Day-Ahead) for 2002 and 2005



Source: OMEL, Spain